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**The Permian-Triassic boundary in continental sedimentary succession at the SE margin of the Central European Basin (the Holy Cross Mountains, Poland)**

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**Supplementary Material 1**

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| **Names of formal units** | **Description\*** |
| **Czerwona Góra Formation** | Definition: succession of red to greyish-red, clast- to mud-supported conglomerates and breccias, locally intercalated with coarse sandstones and/or nodular limestones. In boreholes they form two distinctive horizons (lower and upper) both with clear erosive lower boundary. Origin of name: the unit name comes from conglomerates exposed in an old quarry in Czerwona Góra (“Red Hill”) hill near Chęciny (Figs 1c and 4a), located 13 km south from Kielce. These conglomerates are traditionally known as “Zygmuntówka” (from Latin name “Sigismund”) conglomerates. They were used in the 17th century to make the first column on which the sculpture of King Sigismund III Vasa was placed in Warsaw.Previous names: rocks forming this unit are traditionally called the Zygmuntówka Conglomerates, informally subdivided into the Lower and Upper Conglomerates (Czarnocki, 1923; Kostecka, 1962). The lowermost Triassic Zachełmie Conglomerate Member (Kuleta & Zbroja, 2006) appears to be coeval to the upper horizon of the Czerwona Góra Formation.Stratotypes: the reference section is located in the old quarry at Czerwona Góra (“Red Hill”) northward of Chęciny (Fig. 1c), while the hypostatotypes are postulated at the Jaworznia quarry located westward of Kielce (Fig. 1c) and in boreholes providing the most complete section of this unit, i.e., the Białe Zagłębie 1 well (0 - 42 m, and 60 - 123.7 m) and Ruda Strawczyńska IG-1 well (684.2-691.2 m, and 670 - 675.2 m; Figs 1c, 5 and 6a).Boundaries: the lower boundary of the lower Czerwona Góra Formation is erosive and refers to as the angular unconformity with older Paleozoic rocks, largely the Devonian and Carboniferous strata, nicely exposed in the Kowala quarry (Fig. 4c), however, in the northern HCM conglomerates rest also on the Cambrian, Ordovician and Silurian rocks (Trela & Szczepanik, 2009). The upper boundary of this horizon is at its contact with the Podzamcze or Siodła formations (Fig.5). The lower boundary of the upper Czerwona Góra Formation is erosive with the Siodła and Podzamcze formations or older Paleozoic strata (Fig. 4d), while its upper boundary is gradual or erosive with the Szczukowice or Jaworzna formations (Figs. 4b, 6a,b).Thickness: the unit characterized by a highly variable thickness, ranging from a few meters in the Ruda Strawczyńska IG-1 well through more than 30 m in the Czerwona Góra quarry to over 100 m in the Białe Zagłębie 1 well (Figs 5 and 6; Zbroja *et al.*, 1998).Detailed description: the Czerwona Góra Formation consists of red to greyish-red, polymodal, poorly sorted conglomerate and breccia beds displaying clast-supported framework, tight packing of pebble to cobble-sized clasts (Kostecka, 1962; Głazek & Romanek, 1976, Zbroja *et al.*, 1998). Matrix is poorly sorted, composed of red or brown, medium to coarse sand. The diameter of framework clasts ranges from 1 to 15 cm, and they are commonly sub-angular to sub-rounded in shape. Locally the longest clast axes are aligned parallel to the bedding surface. In places, conglomerates are matrix-supported with medium to coarse sand matrix and chaotically oriented framework clasts. Clasts comprise Devonian limestones and dolostones, with red claystone and grey very fine to fine sandstone fragments present in the northern area (the Kajetanów area). Locally, especially in the upper section of the Czerwona Góra Formation, clasts are made up of reworked Zechstein conglomerates. Conglomerates are well cemented, often with white calcite cement. Locally small (up to several cm) faults filled with calcite are present. In some localities conglomerates are abruptly or gradually overlain by poorly sorted greyish to reddish, medium to coarse grained, often pebbly, sandstones with crude horizontal to low-angle lamination. In places, adjacent to the ancient elevated blocks, the formation developed as breccia owing to shorter transport, e.g. at the Jaworznia quarry, Oblęgór B1 well (Figs 3e,f; Figs 4 a-c).Age: despite the fact that conglomerates of the Czerwona Góra Formation were the subject of numerous studies (Czarnocki, 1923; Kostecka, 1962, 1966; Kozłowski, 1962, Czarniecki *et al.*, 1965; Kowalczewski & Rup, 1989; Zbroja *et al.*, 1998), the age of this unit is not clearly defined to this day. Conglomerates underlying the PZ1 carbonates (Ca1) are postulated to represent the Rotlinged deposits, while the rest of this unit is placed within the Zechstein Group on the basis of *Horridonia horrida* fossils (found in the marine carbonate intercalations within the conglomerate bodies) and relation to the other Permian facies in the HCM (Kostecka, 1962, 1966; Czarniecki *et al.*, 1965; Kowalczewski & Rup 1989). The topmost part of the Czerwona Góra Formation is within the P/T boundary interval (Głazek & Romanek 1976).Regional distribution and correlation: the Czerwona Góra Formation is widespread along the Paleozoic massif of HCM. Besides startotype localities, conglomerates of this unit are exposed in Gałęzice village, on the eastern slope of the Karczówka Hill in Kielce, in the nearby Wiśniówka village located north of Kielce (Fig. 1c) and other locations further east. Moreover, the Czerwona Góra Formation has been documented in several boreholes located north and north-west of the HCM, often interfingering with the Siodła and Podzamcze formations (Figs. 2, 5, 6a,b). The most complete profiles of the Czerwona Góra Formation have been encountered in Białe Zagłębie 1 (0 - 42 m, and 60 - 123.7 m), Gałęzice G-6 (76.85 - 100.4 m), Podzamcze IG-1 (369.85 - 390.6 m), Szczukowice IG-1 (280 - 305.6 m), Ruda Strawczyńska IG-1 (684.2-691.2 m and 670 - 675.2 m) and Oblęgór B1 (44.5-88.4 m) wells (Figs 5, 6a,b).Genetic interpretation: deposits of gravel-dominated braided rivers and rock avalanches of alluvial fan (Kostecka, 1962; Głazek & Romanek, 1976) or fan delta setting with the short-term marine incursions (Zbroja *et al.*, 1998). Some breccias and conglomerates may be also developed as regolith (Szulczewski, 1995) or represent reworked older conglomerates (Szulc *et al.*, 2015). |
| **Podzamcze Formation** | Definition: red, violet-red or pinkish-red, predominantly laminated, calcareous, very fine to medium grained sandstones, intercalated with red, reddish-white mudstones, with locally well-developed calcrete horizons. Subordinate lithologies include matrix- to clast-supported conglomerates, evaporates, and pedogenically altered mudstones and sandstones.Origin of name: from the village Podzamcze located approximately 15 km west of Kielce, where the Podzamcze IG-1 well was drilled (Fig. 1c).Previous names: this interval was assigned to the Zechstein Top Terrigenous Series - PZt and underlying T3r unit of the PZ3 cyclothem (Fig. 2; Kowalczewski & Rup, 1989; Kuleta & Zbroja, 2006).Stratotypes: the stratotype is located in the Podzamcze IG-1 well at depth of 392.6 - 419 m, while the hypostratotypes have been established in the Gałęzice G-6 well at depth 100.4 - 134.2 m and Tumlin Podgrodzie IG-1 well at depth 261 - 307.2 m (Figs 5 and 6). All drilling cores are stored in Polish National Geological Archive in Kielce.Boundaries: at the stratotype section the lower boundary is defined as continuous contact with dark grey and grey Zechstein carbonates, marls and evaporates of the PZ1 or PZ3 cyclothems (Fig. 2). The upper contact is continuous with mudstones of the overlying Siodła Formation (see below) or erosive with upper conglomerates of the Czerwona Góra Formation (Fig. 2). The transition between the Podzamcze and Siodła formation is defined at the first appearance of dusky red, mottled, nodular calcareous siltstone with root structures and calcretes.Thickness: from 15 m in the Szczukowice IG-1 and Zaciszowice IG-1 wells up to 50 m in the Cierchy IG-1 well.Detailed description: at the stratotype sections (and type area), the formation can be characterized by variable succession of red, violet red, pinkish red and/or variegated, calcareous, very fine to medium grained sandstones, locally interbedded with red, reddish-white, light brown and variegated, calcareous mudstones and heteroliths. Sandstone intervals are commonly low angle bedded to locally massive. Very fine-grained sandstone intervals locally contain poor- to well-developed, sub-rounded or elongated, < 5 cm in diameter, light red calcareous nodules, in places developed as layers (calcrets) up to 50 cm thick. Subordinate lithologies include red or pinkish matrix and clasts supported conglomerates (with thickness less than 1.5 m), and dark red to dark dusky red, friable, and highly weathered calcareous claystone/mudstones with small calcareous nodules (<2 cm), clay-skinned slickensides and small root structures developed as rhizohaloes. Mottling is rare, however, can be pervasive in some intervals (<1 m thick). In some wells, the Podzamcze Formation is developed as a heterolithic interval characterized by highly irregular, discontinuous and deformed thin (up to 20 cm thick) white or pink-white calcareous sandstone layers intercalated with red, massive, calcareous and well-cemented mudstones of various thickness (mm-scale up to 20 cm thick). (Figs 3a,b).Age: basing on miospore specimens of the *Lueckisporites virkkiae* Potonié et Klaus Ac and Bc subzones (Fijałkowska-Mader, 1997), the Podzamcze Formation appears to correspond to the PZ3 and PZ4 cyclothems (Fig. 2). The miospore assemblages of the *L. virkkiae* Bc subzone have been reported in the Ruda Strawczyńska IG 1 (709.6 m), Cierchy IG 1 (637.4 m, 638.2m, 640.8 m), Tumlin-Podgrodzie IG 1 (283.4 m, 284.6 m), Siodła IG (181.1 m, 183.5 m; Fig. 6), Zabłocie IG 1 (50.6 m, 52.2 m) and Zachełmie IG 1 (139.3 m, 145.4 m) wells. They are dominated by conifer pollen grains of the *Lueckisporites virkkiae* Potonié et Klaus, represented mainly by Ab (Fig. 7a) and B norms (after Visscher 1971: Fig. 7b), including the index Bc norm (Fig. 7c). They are accompanied by high frequency specimens of the *Lunatisporites* (Figs 7f, g), *Strotersporites* (Fig. 7d), *Protohaploxypinus* (Fig. 7e), *Gardenasporites* (Fig. 7j) and characteristic *Jugasporites lueckoides* Klaus (Fig. 7h) as well as green algae representing *Reduviasporonites catelunatus* Wilson (Fig. 7j).Regional distribution: the Podzamcze Formation does not crop out at the surface, however, it is widely distributed in the boreholes located in the Gałęzice-Bolechowice and Piekoszów synclines as well as in the northern margin of the HCM (Fig. 1c): the Cierchy IG-1 ( 610.9 - 60.7 m), Stachura IG-1 (563.4 - 600.1 m), Ruda Strawczyńska-1 (694.2 - 738.5 m), Jaworzna IG-1 (213.8 - 243.8 m), Siodła IG-1 (160.2 - 187.2 m), Goleniawy IG-1 (423.6 - 448.5 m), Jaworze IG-1 (307.5 - 336.3 m), Łączna-Zaszosie (359.7 - 389 m), Piekoszów IG-1 (493.4 - 515.6 m), Szczukowice IG-1(305.5 - 320.5 m) and Sitkówka 1 (45 - 93 m) wells (Figs 5, 6a and b). Correlation: considering the occurrence of *Lueckisporites virkkiae* Ac and Bc subzones, the Podzamcze Formation can be correlated with the Zechstein PZ3, PZ4a and lower PZ4b units from the Polish Lowland (see Wagner, 1994).Genetic interpretation: mudflats developed in coastal to continental sabkha/playa settings, locally eroded by sand-dominated ephemeral streams/rivers (Kowalczewski & Rup, 1989; Kuleta & Zbroja, 2006; Trela & Fijałkowska-Mader, 2017). |
| **Siodła Formation** | Definition: reddish or variegated calcareous mudstones with numerous root-related structures, carbonate nodules and well-developed calcrets. Thin sandstones and conglomerates (with thicknesses less than 2 m) are also observed.Origin of name: from the Siodła village located ~15 km north-westward of Kielce, where the Siodła IG-1 well was drilled (Fig. 1c).Previous names: the Permian Top Terrigenous Series - PZt (Kowalczewski & Rup, 1989); the lowermost Triassic “A0” unit in Nawrocki *et al.*, (2003) and the Siodła formation in Kuleta & Zbroja (2006).Stratotypes: the stratotype is in Siodła IG-1 well at depth of 128.4 - 159.2 m (Fig. 1c); drilling core stored in Polish National Geological Archive in Kielce. Hypostratotypes are established in the Tumlin-Podgrodzie IG-1 (208.2-261 m) and Cierchy IG-1 (572.5 - 610.5 m) wells (Fig. 5).Thickness: from 9 m in the Ruda Strawczyńska IG-1 well up to 52 m in the Tumlin-Podgrodzie IG-1 well (Fig. 5).Boundaries: at the stratotype sections the lower boundary is continuous with the underlying Podzamcze Formation (see above), while upper boundary is erosive with the overlying Jaworzna Formation and the upper Czerwona Góra Formation (Fig. 5). In the Stachura IG-1 and Ruda Strawczyńska 1 wells this unit is placed between relatively thick conglomerate horizons of the Czerwona Góra Formation (Fig. 5).Detailed description: a succession of dusky red, reddish, pinkish-red or variegated, highly calcareous siltstones or fine-grained sandstones. They commonly contain calcareous sub-rounded nodules ranging from a few millimeters up to 10 cm in diameter. Nodules often coalesce forming up to 40 cm thick calcrete layers. Root structures are developed as the root-cast filled with red silty material, associated with rhizoconcretions and/or rhizohaloes with white and bluish mottles (Kuleta & Zbroja, 2006, Trela & Fijałkowska-Mader, 2017). Calcrete intervals are commonly spotted by numerous small (< 5 mm) sparite-filled calcite tubules. Siltstones are locally intercalated with red, dusky red or pinky-red, calcareous, horizontally or low-angle cross laminated sandstones commonly containing small rip-up mud clasts. Locally, mud- to clast-supported conglomerates (up to 1 m thick), composed of sub-rounded or rounded nodules and/or limestone clasts up to 5 cm in diameter can be observed (Kuleta & Zbroja 2006;Trela and Fijałkowska-Mader, 2017)(Fig. 3c, d).Age: this unit is biostratigraphically barren. Magnetostratigraphic data locate the Siodła Formation in the lowermost part of normal polarity magnetozone Tbn1 (Nawrocki, 1997; Nawrocki *et al.*, 2003), which was the major argument for correlation of this unit with the lowermost Triassic (Kuleta & Zbroja, 2006). However, based on a new magnetostratigraphic scheme of the Upper Permian/Lower Triassic strata by Hounslow & Balabanov (2018), and their relation to the biostratigraphically dated Jaworzna Formation (see below), the Siodła Formation is likely to be the latest Permian unit as postulated by Kowalczewski & Rup (1989), Ptaszyński & Niedźwiedzki (2006), Trela & Fijałkowska-Mader (2017).Regional distribution: no surface outcrops are currently known. The Siodła Formation has been identified in the northern part of the HCM region, however, the determination of its northward distribution is hampered by the lack of drilling cores, while the southern boundary is related to the outline of the Paleozoic massif. Beside stratotype sections, the Siodła Formation occurs in the the Ruda Strawczyńska 1 (675.2 - 684.2 m), Jaworze IG-1 (281.7-307.5 m), Jaworzna IG-1 (175.8-213.8 m) and Zaciszowica IG-1 (53.7 - 81 m) and Ostojów IG-1 (275.8 - 291.6 m) wells (Fig. 5).Correlation: considering the magnetostratigraphic data, the Siodła Formation may be correlated with informal “PZt” and “PZS4” units in the central part of the Zechstein basin and the Rewal Formation in the Polish Lowland area (Wagner, 1994; Wagner & Peryt, 1997).Genetic interpretation: pedogenically overprinted distal mudflats with intensive rhizoturbation, developed in a playa lake setting truncated by ephemeral streams (Kuleta & Zbroja, 2006; Trela & Fijałkowska-Mader, 2017). |
| **Jaworzna Formation** | Definition: succession of light dusky to dusky red, fine to medium grained to locally coarse-grained quartzite sandstones intercalated with dark red or variegated mudstones and locally grey claystones.Origin of name: from the Jaworzna village and the Jaworzna IG-1 well located ~14 km north-westward of Kielce (Fig.1c).Previous name: the transitional (or “passage”) beds (Senkowiczowa& Ślączka, 1962; Senkowiczowa, 1970), “sub-oolitic beds” (Fuglewicz, 1980), A1 complex (Nawrocki *et al.*, 2003) and the Jaworzna Formation (Kuleta and Zbroja, 2006).Stratotypes: the stratotype of that formation is located in the Jaworzna IG-1 well (also incorrectly known as the Jaworzno IG-1) at depth of 154.7-175.8 m (the core is stored in Polish National Geological Archive in Kielce). Hypostratotypes are in the Zachełmie quarry and Cierchy IG-1 well (529.2-565.4 m). Boundaries: the lower boundary is erosive with the Siodła Formation or the Szczukowice Formation and continuous with the underlying Czerwona Góra Formation (Fig. 5). The upper boundary is erosive with sandstones of the Zagnańsk Formation (Figs. 4b,e, 5). Thickness: from 6 m in the Zachełmie quarry up to 36.2 m in the Cierchy IG-1 well. Thickness is highly variable and depends on erosion depth of the overlying Zagnańsk Formation. Detailed description: red, dusky red, dusky brown or pinkish red, non- to slightly calcareous, quartzitic and/or micaceous, very fine to medium-grained, very thin to thin, horizontal or cross-laminated sandstones. Sandstones are locally pebbly, comprising red to dark brown mud clasts. The ripple cross-lamination is sporadically visible. Locally, sandstone beds are interbedded with dark red-brown, friable, micaceous massive or laminated mudstones, which in some cases may predominate over the sandstones (Figs. 3h, 4e).Age: the spore-pollen specimens of the *Lundbladispora obsoleta* and *Protohaploxypinus pantii* zone (Fijałkowska, 1994a,b) clearly indicate the Early Triassic (Induan) age of this unit. The assemblage of the *obsoleta - pantii* zone has been recognized in the Tumlin-Podgrodzie IG 1 well (190.7 m, 198.2 m, 204.4 m), Jaworzna IG 1 well (157.0 m-163.2 m, Łączna-Zaszosie IG 1(239.7 m), Ostojów IG 1 (265.5 m, 266.3 m; Fig. 6) and Jaworze IG 1 (260.0 m) wells. The specimens of *Protohaploxypinus* (Figs 7o, p) and *Lunatisporites* (Fig. 7q) are common in this pollen grain assemblage, while the lycopsid spores of *Lundbladispora* *obsoleta* Balme (Fig. 7k), *L. willmotti* Balme (Fig. 7l), *Densoisporites playfordii* (Balme) Dettmann (Fig. 7m) and *Kraeuselisporites cuspidus* Balme (Fig. 7n) as well as cycadalean pollen of *Cycadopites* (Fig. 7r) are less abundant. Furthermore, algae of *R. catelunatus* Wilson and *Schizospora* (Fig. 7s), and fungi spores of aff. *Microsporonites* (Fig. 7t) are common. The quantitatively important element of the palynological assemblages in the Jaworzna Formation are reworked palynomorphs, including the Devonian (Fig.7q) and Carboniferous spores (Fig. 7u) as well as acritarchs of *Veryhachium, Baltisphaeridium*, *Micrhystridium* (Figs 7w, x), and chitinozoans (Fig. 7y). The cited acritarch taxa are long-range forms and common specimens of the Ordovician and Silurian microphytoplankton assemblages in the HCM (Trela & Szczepanik, 2009). Moreover, Ptaszyński ~~and~~ & Niedźwiedzki (2004) recognized conchostracan fossils of *Falsisca eotriassica, F. postera* and *F. verchojanica* in mudstones of the Jaworzna Formation (the Zachełmie quarry), and postulate the transition from the Permian to Triassic within this unit. It is noteworthy that these taxa are accompanied by *Euestheria* *gutta* Lutkevitch and *Euestheria gutta oertlii* Kozur (Ptaszyński & Niedźwiedzki, 2004). The chronostratigraphic position of the Jaworzna Formation is supported by magnetostratigraphic data, which locate it within the earliest Triassic normal polarity magnetozone Tbn1 (Nawrocki, 1997; Nawrocki *et al.*, 2003).Regional distribution: the Jaworzna Formation was recognised only in the northern part of the studied area, eastward of the Stachura IG-1. The formation is well documented in the Goleniawy IG-1 (379-407.2 m), Siodła IG-1 (97.3-128.4 m), Łączna-Zaszosie IG-1 (326.2-340.1 m) and Ostojów IG-1 (259.3 - 275.7 m) wells (Fig. 5).Correlation: the Jaworzna Formation is a lateral equivalent of the Szczukowice Formation (see below) and is correlated with the informal Opoczno Formation from the NW distal localities (Kuleta & Zboja, 2006). This formation may be also correlated with the lower part of the Baltic Formation in the central and northern part of the Polish segment of the CEB.Genetic interpretation: sedimentological features of this unit, described by Szulczewski (1995), Kuleta *et al.* (2006), Becker & Złonkiewicz (2015), indicate its deposition on the distal alluvial fan consisting of sand-dominated braided river environment, flood sheets and terminal splays (Trela & Fijałkowska-Mader 2017). |
| **Szczukowice Formation** | Definition**:** red or dusky red, very fine to fine grained, non- to slightly calcareous, highly micaceous, laminated mudstones and sandstones, locally pedogentically altered. Origin of name: from the Szczukowice village and the Szczukowice IG-1 well located ~10 km south-west of Kielce (Fig. 1C), where the formation is present.Previous names: the upper mudstones and shales (Szaniawski, 1963), “Z4” complex by Kostecka (1966), and the Szczukowice formation by Kuleta & Zbroja (2006).Stratotypes: the startotype section in the Szczukowice IG-1 well at depth of 253.1-280.0 m (the core is stored in Polish National Geological Archive in Kielce). Hypostratotypes are located in the Jaworznia quarry, 7 km westward of Kielce (Fig.1C) and in the Gałęzice G-6 well at depth of 14.2 - 76.85 m (Fig 4d).Boundaries: the lower boundary is concordant with the upper conglomerates of the Czerwona Góra Formation, while the upper boundary is erosive with the Zagnańsk Formation. Locally, the Szczukowice Formation is overlain by the Jaworzna Formation along the erosive contact (see the Cierchy IG-1 well; Fig.5).Thickness: from 3.2 m in the Cierchy IG-1 up to 62.7 m in the Gałęzice G-6 well (Figs. 5-6a).Detailed description**:** the bulk of this formation is made up of red to dusky red, very fine to fine grained, well sorted, non- to slightly calcareous, highly micaceous, thin bedded, horizontally laminated sandstones, as well as red non- to slightly calcareous, micaceous, massive and laminated, highly friable mudstones locally with small (less than 2 cm in diameter) irregular to sub-rounded calcareous nodules. The lower part of the succession commonly shows distinct heterolithic bedding (siltstone/very fine micaceous sandstones). In the upper part, siltstone intervals are often pedogentically altered (Fig. 3g).Age: biostratigraphically barren unit. Based on the relationship with the Jaworzna, Czerwona Góra and Zagnańsk formations and the presence of weakly developed soils (see discussion), the age of the formation was determined at the Early Triassic (Induan).Regional distribution: the Szczukowice Formation is limited to the western and southern part of the HCM, i.e., the Piekoszów and Gałęzice-Bolechowice synclines (Fig. 1c). Beside of the stratotype sections this unit has also been recognized in the Podzamcze IG-1 well at depth of 337.25 - 369.85 m, the Piekoszów IG-1 well at depth of 448.8-483 m and the Cierchy IG-1 well at 565.4-568.6 m depth (Figs 5-6).Correlations: the Szczukowice Formation is a lateral equivalent to the Jaworzna Formation and correlated with the Opoczno formation occurring in the NW distal margin of the HCM (Kuleta & Zbroja, 2006). In the Polish Lowland area, the lowermost Baltic Formation appears to be a lithostratigraphic equivalent of the Szczukowice Formation (see Wagner, 1994). Genetic interpretation: Kuleta and Zbroja (2006) interpreted the Szczukowice Formation as lacustrine mudstones with an addition of sandy fluvial deposits. However, sedimentary and stratigraphic features indicate that this formation represents a distal to locally proximal floodplain of an alluvial fan with sand-dominated terminal splays. |

\* For references and figures please refer to main article. All depths are in meters below surface level.